IDENTIFYING PREFERRED HABITATS FOR HAWAII'S DEEP COMMERCIAL BOTTOMFISH SPECIES

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By

William Francis Xavier E. Misa

Thesis Advisor

Dr. Jeffrey C. Drazen

I certify that I have read this thesis and that, in my opinion, it is satisfactory in the scope and quality as a thesis for the degree of Bachelor of Science in Global Environmental Science.

THESIS ADVISOR

_____

Dr. Jeffrey C. Drazen

Department of Oceanography

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ABSTRACT

Hawaii's deep commercial bottomfish fishery includes 6 species snappers, Opakapaka (*Pristipomoides filamentosus*), Kalekale (*Pristipomoides sieboldii*), Gindai (*Pristipomoides zonatus*), Onaga (*Etelis coruscans*), Ehu (*Etelis carbunculus*), and Lehi (*Aphareus rutilans*), and 1 grouper, Hapuupuu (*Ephinephelus quernus*). With the observed decline in Deep 7 populations around the main Hawaiian Islands, the State of Hawaii established 12 bottomfish restricted fishing areas (BRFAs) selected using the Essential Fish Habitat (EFH) concept. The EFH definition for all Hawaii bottomfish is "all bottom waters between 100 and 400 meters". This has been defined in general due to lack of available information on bottomfish ecology. The goal of this study is to quantitatively identify species-specific habitat preferences using in-situ videographic techniques to aid in the redefinition of the essential fish habitat for Hawaii's deep commercial bottomfish. Deep 7 population density data from three BRFAs gathered with the use of a Bottom Camera Bait Station (BOTCAM) were correlated to multibeam classified and visually classified habitats in order to identify habitat preferences. Four basic habitat types were used on the basis of substrate hardness and slope: hard-high, hard-low, soft-high and soft-low. Opakapaka and Onaga showed a preference for hard substrates but no slope preference. Kalekale and Hapuupuu showed a strong preference for hard-high habitats. Gindai showed a suggestion of hard-high preference while Ehu and Lehi exhibited no significant preference for any of the basic habitats. With the species-specific habitat preferences seen, new elements such as hardness of substrate and slope may then be included in a modified EFH definition for Hawaii bottomfish in an improved ecological management approach.

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CHAPTER 1

INTRODUCTION

Hawaii's bottomfish fishery is a deepwater handline fishery that targets a multispecies group of fishes including Snappers (*Lutjanidae*), Groupers (*Serranidae*) and Jacks (*Carangidae*) (Haight et al., 1993a). The deep bottomfish species preferred commercially include 6 snappers, namely Opakapaka (*Pristipomoides filamentosus*), Kalekale (*Pristipomoides sieboldii*), Gindai (*Pristipomoides zonatus*), Onaga (*Etelis coruscans*), Ehu (*Etelis carbunculus*), and Lehi (*Aphareus rutilans*), and 1 grouper, Hapuupuu (*Ephinephelus quernus*). These 7 bottomfish species are collectively known as the deep 7. Most of the commercially important species have a relatively high age of maturity, long life span and slow growth rate which make these fish highly susceptible to overfishing (Haight et al., 1993a). Hawaii has a long history of both commercial and recreational bottomfishing. Since the early 20th century Hawaii's bottomfish have been commercially exploited. In the 1930's fleets of vessels fished for bottomfish throughout Hawaii's archipelago extending into the Northwestern Hawaiian Islands. Landings peaked in the early 1950's at about 500 metric tons, and declined steadily throughout the mid-1970's. Towards the end of the 1970's, fishing pressure was highest at banks closest to the main Hawaiian Island ports. The fishery rapidly expanded in the 1980's with landings peaking in 1987 at over 600 metric tons (Haight et al., 1993a; Figure 1). Catch per unit effort (CPUE) data from commercial fishermen catch reports along with the spawning potential ratio (SPR) for a particular bottomfish species have been used to

monitor bottomfish stocks. The spawning potential ratio is a measure of the proportion of spawning size fish in a given population. With the increasing fishing pressure, a variety of management measures have been taken to ensure the sustainability of Hawaii's bottomfish resources.

Figure 1. Annual commercial bottomfish landings from the entire Hawaiian Archipelago, 1948-1990 (Haight et al., 1993a).

Limits in fish catch size, access limitations to fishing grounds such as that in the Northwestern Hawaiian Islands where a limited number of permits are available, required fish catch reports from commercial fishermen and as of 2007 recreational fishermen as well, and seasonal and permanent area closures are among the measures taken in rehabilitating Hawaii's bottomfish stocks (Parke, 2007). In 1998, following an assessment by the Marine Fisheries Service that stocks of Ehu and Onaga were approaching a low spawning potential ratio in the main Hawaiian Islands, the State of

Hawaii Department of Land and Natural Resources (DLNR) implemented bottomfish restricted fishing areas (BRFAs) (Parke, 2007). The creation of the initial 19 BRFAs in 1998 was an attempt by the state to eliminate fishing in certain geographic areas that might be high-quality bottomfish habitat and to help ensure long term-sustainability of bottomfish stocks (Parke, 2007). Moffit et al (2006) determined that despite the implementation of 19 BRFAs, bottomfish overfishing was still occurring in the main Hawaiian Islands, and a reduction of bottomfish mortality by at least 24% was needed to end overfishing. The DLNR responded by redesigning the system of BRFAs, reducing the overall number to 12 (Figure 2), but increasing the size and quality of the areas closed to bottomfishing (Parke, 2007).

Figure 2. 12 bottomfish restricted fishing areas in the Main Hawaiian Islands established in 2007 (Figure from Hawaii DLNR - Division of Aquatic Resources website).

Research techniques used in assessing bottomfish stocks have progressed over the years. Catch per unit fishing effort (CPUE) of commercial fishermen or research vessel surveys has been used as an index of stock abundance (Haight et al., 1993a). Incomplete reporting of bottomfish catch and the "under-the-table" selling of fish by recreational fishermen confound the accuracy of the catch reporting system (Haight et al., 1993a). The use of a CPUE method for assessing bottomfish stocks may therefore generate some inaccuracy. Furthermore, CPUE indices are known to be hyperstable and readily mask declines in stock status (Walters and Martell, 2004). Ralston and Polovina's (1982) Schaefer surplus production model attempted to assess main Hawaiian Island deepwater snapper stocks using parameters estimated from a linear regression of yearly CPUE. Beverton and Holt's (1957) dynamic pool modeling approach, widely used in the 1980's, involved equations that incorporated a growth coefficient, fish mortality data, and fish age. Data needed for these types of methods for bottomfish stock assessment still relied highly upon reports filed by commercial fishermen and therefore did not yield reliable results. In 1987, Wetherall et al. used catch length frequency data to estimate bottomfish stocks. The Wetherall et al. (1987) method still relied on CPUE data, and therefore, due to bias in catch reporting, did not reflect the dynamic stock (Haight et al., 1993a). There is an evident need for a dynamic stock estimation method that does not rely on CPUE data (Haight et al., 1993a). Underwater stereo-video systems are the current technology being used to assess fish stocks (e.g. Ellis and DeMartini, 1995; Willis et al., 2000; Willis and Babcock, 2000). These systems give us the ability to make in-situ assessments of fish populations and improve our ability to monitor commercially important fish stocks.

With the implementation of the Magnuson-Stevens Fishery Conservation and Management Act of 1996, federal fishery management plans were required to identify the essential fish habitat (EFH) for their fishery species to bring an ecological perspective to fisheries management. This act defines an EFH as "*those waters and substrate necessary for fish spawning, feeding or growth to maturity*" (Rosenberg et al., 2000). The goal of the Magnuson-Stevens Fishery Conservation and Management Act was to bring an ecological approach to fisheries management. The Hawaiian Islands bottomfish fishery typically targets a range of snappers and groupers that live between the depths of 100 and 400 meters. For this reason, the EFH definition for all Hawaii bottomfish is "*all bottom waters between 100 and 400 meters*". The EFH for the Hawaiian bottomfish fishery has been defined in general due to lack of available information on their ecology (Parks, 2002). EFH definitions are designed to guide management decisions on the protection and sustainable exploitation of fishery resources and therefore need to be as complete and as specific as possible (Kelley et al., 2006). Many bottomfish species have been found to associate with certain benthic features, such as high-relief and hard-bottom slopes (Kelley et al., 2006). Previous studies have shown that this habitat type correlates to high bottomfish abundance (Polovina et al., 1985). Parke (2007) describes a suitable habitat for adult bottomfish as being depth between 100 and 400 meters, a slope of greater than 20^{o}, and a hard bottom.

The goal of my thesis is to quantitatively identify species-specific habitat preferences using in-situ videographic techniques to aid in the redefinition of the essential fish habitat for Hawaii's deep commercial bottomfish. Identifying individual species preferences is essential in improving the ecological context of bottomfish fisheries

management. Based on the literature available, the working hypothesis of this paper is that each of the deep 7 will exhibit a preference for high slopes and hard substrates which is consistent with Parke (2007)'s definition of suitable bottomfish habitats. Relative abundance data will be correlated to habitat characteristics (hardness of substrate, slope and depth) to identify preferred habitats within and nearby 3 of the 12 BRFAs (BRFA B – Ni'ihau, BRFA D – Ka'ena Pt., BRFA E – Makapu'u Pt.).

CHAPTER 2

METHODS

When assessing the effectiveness of the original 19 BRFAs in 2005, the Department of Land and Natural Resources (DLNR) contracted research through the University of Hawai‘i to conduct bottom habitat scans and create maps of the areas where bottomfish occur. Interviews with bottomfishers and a review of commercial landings data was also conducted by the DLNR (DLNR, 2005). The data provided a basis for evaluating habitats within the existing BRFAs and identifying new areas that would make better BRFAs. Of the 12 improved BRFAs implemented in 2007, 3 are the focus of this study. BRFA B (Figure 3) is a continuing closed area from 1998 formerly referred to as RFA 1. Boundary modifications have increased the amount of protected EFH area from 25.4 to 26.4 km^2. Onaga, ehu, gindai, kalekale, hapuupuu, and opakapaka have all been confirmed by fishing surveys to be present within its boundaries (Kelley, unpublished data). BRFA D (Figure 4) is a new RFA that closes an area off Ka‘ena Point, Oahu previously open to fishing. Catches of onaga, ehu and opakapaka have been confirmed in this area (Kelley, unpublished data). BRFA E (Figure 5) is located out from East O‘ahu between Lanikai and Makapu‘u Pt. The new boundaries completely enclose the previous RFA 6. BRFA E contains an important onaga breeding ground and ehu, opakapaka and kalekale have been noted in this area (Kelley, unpublished data).

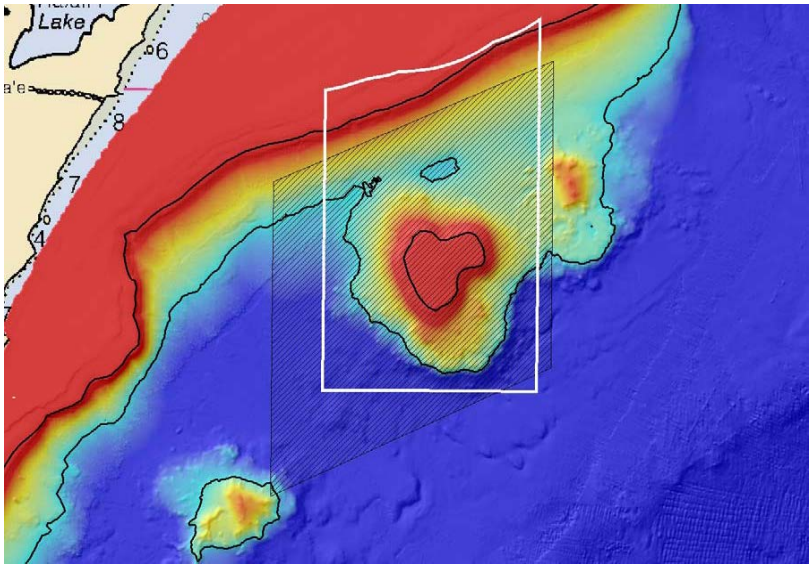

Figure 3. BRFA B (white polygon). Hatched polygon shows location of old RFA 1. Black contour lines are the 100 m and 400 m bottomfish EFH boundaries (Drazen and Kelley, 2007).

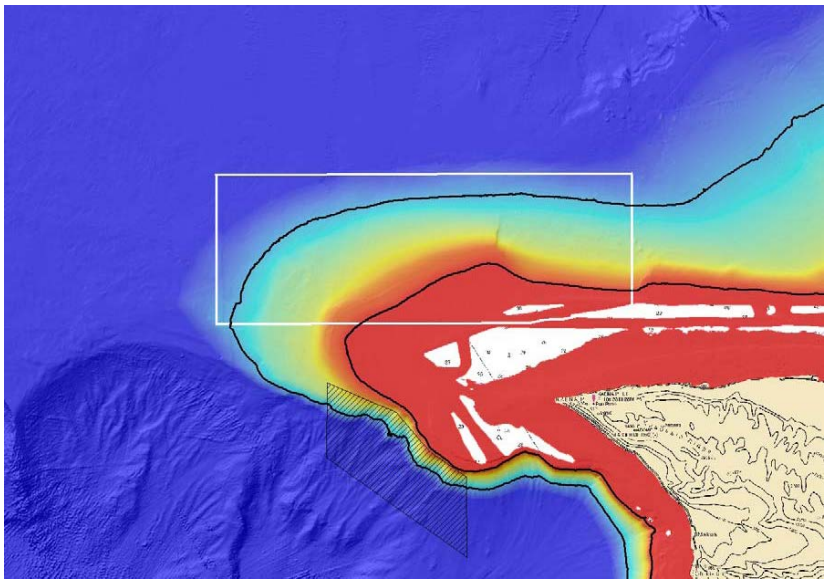

Figure 4. BRFA D (white polygon). Hatched polygon shows location of old RFA 4. Black contour lines are the 100 m and 400 m bottomfish EFH boundaries (Drazen and Kelley, 2007).

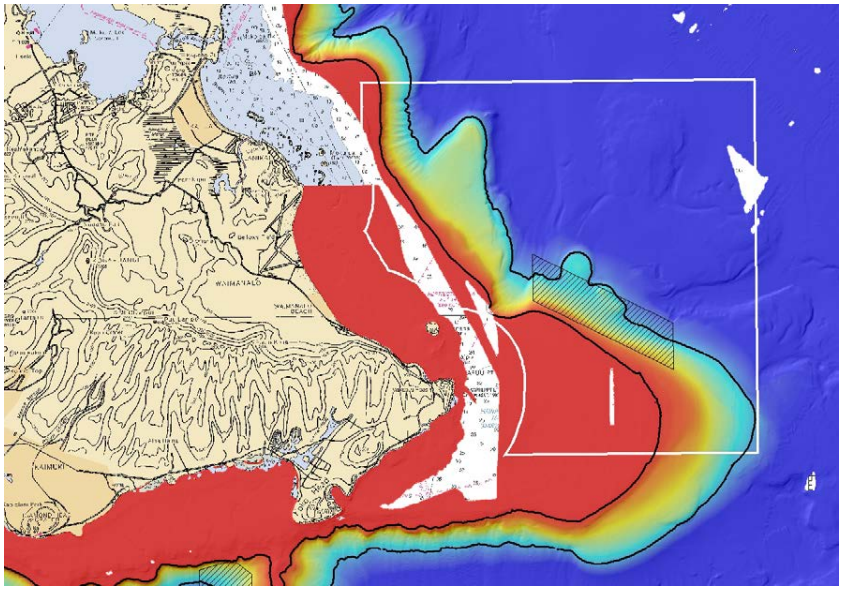

Figure 5. BRFA E (white polygon). Hatched polygon shows location of old RFA 6. Black contour lines are the 100 m and 400 m bottomfish EFH boundaries (Drazen and Kelley, 2007).

The Bottom Camera Bait Station (BOTCAM) (Figure 6), developed by Danny Merritt (Merritt, 2005) and NOAA's Pacific Islands Fisheries Science Center (PIFSC) Coral Reef Ecosystem Division (CRED), is a remote fully automated stereo-video baited camera system with an operating depth of 350 meters and is deployed on the seafloor to monitor commercially important bottomfish (Drazen and Kelley, 2007). It makes use of ambient light and is operational on multiple bottom types including steep slopes and high relief. Upon deployment the BOTCAM unit sits parallel to the seafloor about 3 meters off the bottom, generating a horizontal field of view of the bottom environment with no fixed depth of field. It records 30-45 minutes of continuous video at each deployment location. Depth data is taken from a Sea-Bird CTD profiler attached to the BOTCAM unit. The BOTCAM is a non-extractive system that allows us to make dynamic bottomfish

abundance estimates within actual bottomfish habitats and inside no fishing zones. It is also a means by which habitats can be visually characterized. Further details of the BOTCAM's design can be found at http://www.pifsc.noaa.gov/cred/botcam.php and in Merritt (2005).

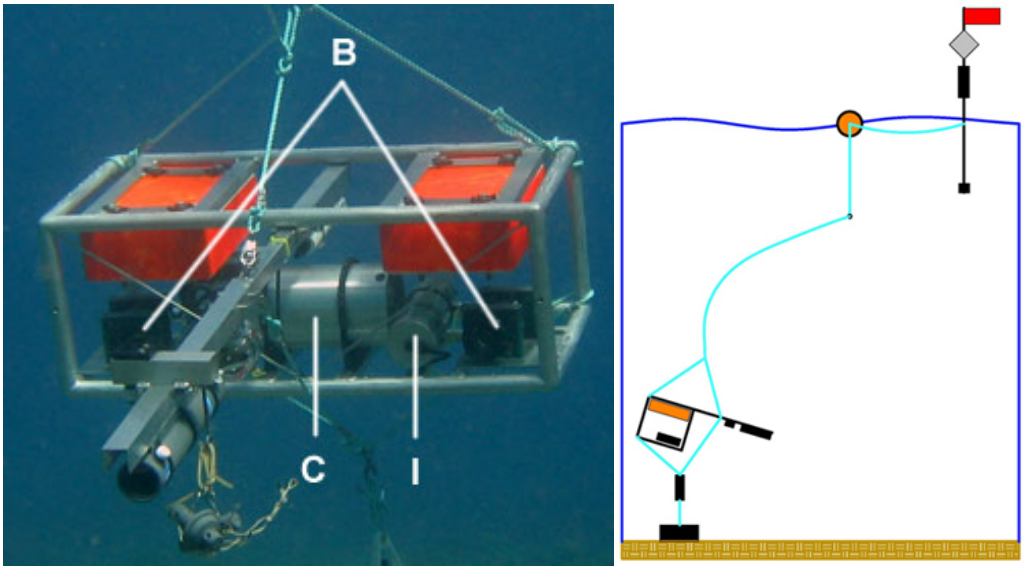

Figure 6. a. Bottom Camera Bait Station (BOTCAM), b. BOTCAM deployment schematic (not to scale) (Photo and deployment diagram from NOAA PIFSC website).

Habitat characterization was done in 2 ways: multibeam mapping and visual observation of BOTCAM videos. An almost complete set of multibeam and sidescan sonar data has been collected in the main Hawaiian Islands over the last decade by the Pacific Islands Benthic Habitat Mapping Group, the University of Hawaii Undersea Research Laboratory (HURL), and the Hawaii Mapping Research Group (Parke, 2007). Depth, substrate hardness, and slope are all habitat variables that can be determined from

the bathymetry and backscatter data. Four simplified habitat types were determined: hard substrate with high slope (>20°), hard substrate with low slope (<=20°), soft substrate with high slope, and soft substrate with low slope. Using ArcGIS, the area in and around BRFAs were divided into 200x200 meter grids and each assigned a habitat type corresponding to the habitat covering the majority of the grid. The 200x200 meter grid size was chosen on the assumption that there would be no attraction of fish from outside this area to the bait. Visual observation of habitat from BOTCAM videos were categorized into the same basic habitats generated from multibeam data. Two reviewers independently categorize visually observed habitat types through video recorded per BOTCAM deployment. Other habitat characteristics such as primary and secondary substrate types (i.e. bedrock, cobbles/pebbles, or sandy sediment), vertical substrate relief and the presence of cavities are also recorded but were not used for the purpose of this study so that a direct comparison can be made between simplified habitats determined by multibeam data and visual observation. Figure 7 shows frame grab examples of each habitat classification as observed through BOTCAM video.

The videos are reviewed in the laboratory (Deep Portal software, Deep-Development Inc, Canada) to estimate bottomfish relative abundance. First arrival times and maximum number counts (N_{max}) are taken for each species identified. The first arrival time is the time post touchdown of the BOTCAM when a species is first observed. First arrival times have previously been used as measures of fish abundance as they exhibit an inverse relationship with abundance (Ellis and DeMartini, 1995; Yau et al., 2001). The use of maximum number counts or N_{max} is another method of determining relative fish abundance. N_{max} is the highest count of a single species observed at any

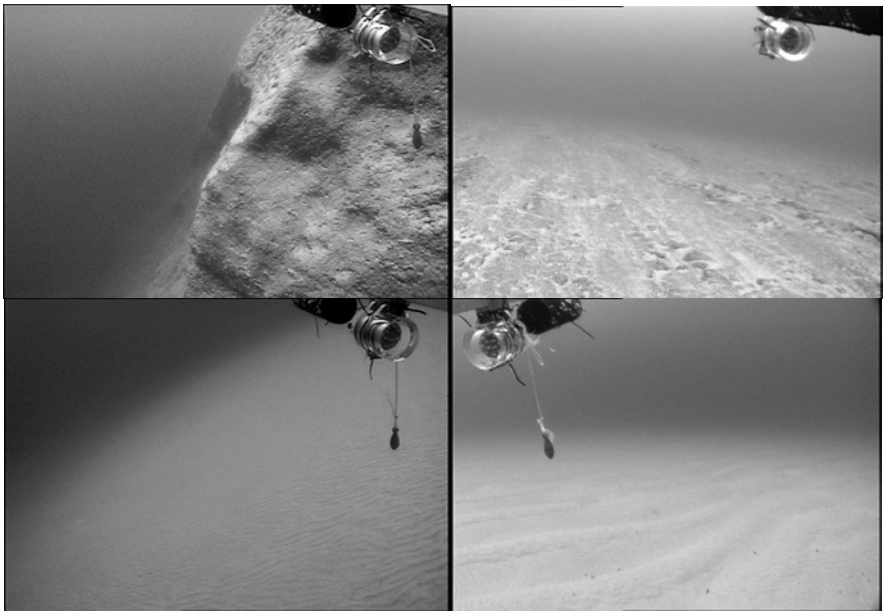

Figure 7. Habitat classifications observed through BOTCAM video. (Top-left = hard-high; Top-right = hard-low; Bottom-left = soft-high; Bottom-right = soft-low).

point throughout the entire duration of video. Ellis and DeMartini (1995), Cappo et al. (2000), Willis et al. (2000), Willis and Babcock (2000) and Yau et al. (2001) found that N_{max} positively correlated with fish density. This parameter also correlated best to the traditional CPUE parameter used in fishing surveys (Ellis and DeMartini, 1995). Through the use of N_{max}, the potential problem of counting the same fish twice as it enters and re-enters the camera's field of view can also be avoided. Changes in the numbers of fish present at the camera throughout the deployment are estimated by recording N_{max} at one minute intervals.

A random stratified sampling approach was used to locate BOTCAM sampling locations. The 100 to 300 meter depth range was sampled 32 times inside and 32 times outside but adjacent to each BRFA. Although the EFH for Hawaii deep bottomfish extends from 100 to 400 meters, the BOTCAM has an operating depth of 350 meters and

therefore limited the allowable sampling depth range. The deployments targeted randomly selected grid centroids. 12 hard-high, 8 hard-low, 8 soft-high, and 4 soft-low grids were targeted inside and outside each BRFA. BRFA B successfully followed the deployment design while BRFA D and E had to be adjusted based on the number of available grids (Table 1) of each basic habitat type.

Table 1. Summary of BOTCAM deployments in BRFA B, BRFA D and BRFA E

BRFA B	**Inside RFA**	**Out North**	**Out South**
Hard-high	12	6	6
Hard-low	8	4	4
Soft-high	8	4	4
Soft-low	4	2	2
BRFA D	**Inside RFA**	**Out North**	**Out South**
Hard-high	0	2*	10
Hard-low	26	4	4
Soft-high	2*	0	8
Soft-low	4	2	2
BRFA E	**Inside RFA**	**Out North**	**Out South**
Hard-high	8*	6	6
Hard-low	10	4	4
Soft-high	10	4	4
Soft-low	4	2	2

* multiple deployments in same grid

A depth distribution was identified for each species and abundance analyses were carried out within the defined species-specific depth ranges. 20 meter depth bins from 100 to 300 meters were plotted with corresponding N_{max} for each species. Bins where a species did not occur on either end of the bin spectrum were then eliminated. If a zero-fish bin occurred between 2 bins where fish were present, this bin was kept. A species-

specific depth distribution was then defined. Data from BOTCAM deployments within the defined depth range of each species were then statistically analyzed (Table 2).

In order to assess habitat associations, species abundance was compared across habitat types and statistical methods were applied to determine significant differences. For each species, mean N_{max} was compared between habitat types (for both multibeam and visually classified habitat data sets). The distribution of N_{max} values for each habitat type and species was non-normal. This was consistent with the patchy, non-normal fish distribution observed by Willis et al. (2000). Non-parametric statistics are therefore required for analysis. The Kruskall-Wallis ANOVA was used first to determine the existence of statistically significant differences ($p<0.05$) across all 4 habitat types in each species for both multibeam and visual habitat data sets. Where statistically significant differences were found, further statistical analyses to compare pairs of habitat types were done using the Mann-Whitney U-test.

CHAPTER 3

RESULTS

The depth distributions for each species within the 100 to 300 meter range varied (figure 8). Opakapaka was mainly observed at depths less than 200 meters while its congener Kalekale was observed at greater depths. Gindai showed the smallest distribution range between 200 and 259 meters. Ehu and Onaga both occurred predominantly deeper than 200 meters. Lehi, although rarely seen, occurred in both shallower and deeper depths while Hapuupuu consistently occurred from 120 meters to 239 meters.

There is a clear difference in the classification of habitat types between multibeam mapping and visual observation from BOTCAM video (Table 2). There is only a 61.5 percent overall agreement between multibeam and visual habitat classifications. Taken separately, hardness of substrate agreed 67.7 percent of the time while slope had 89.1 percent agreement.

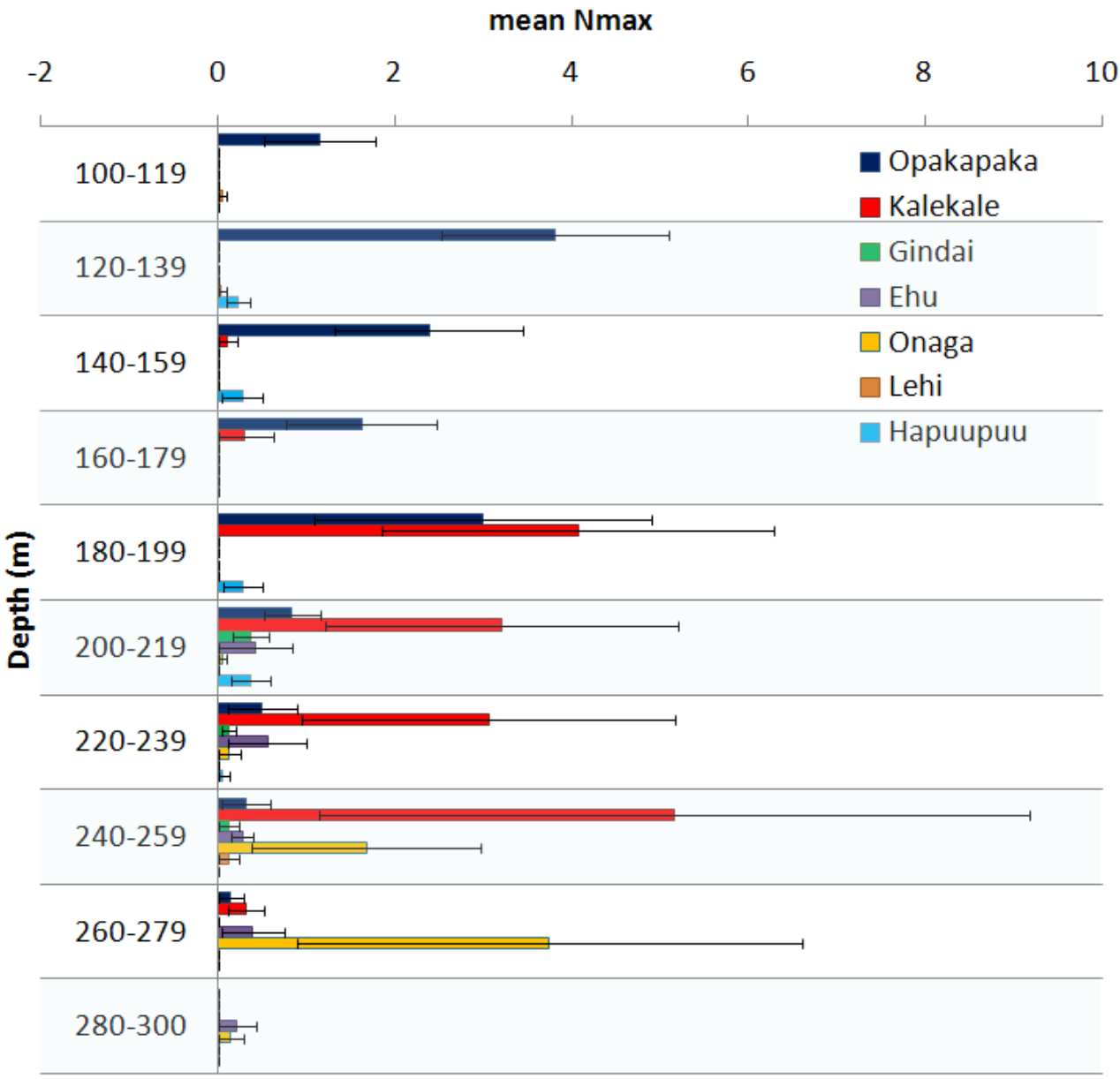

Figure 8. Deep 7 depth distributions. N_{max} as a function of depth between a 100 to 300 meter depth range.

Table 2. Total number of BOTCAM deployments analyzed per species per habitat type within defined species depth ranges

Multibeam	Opakapaka	Kalekale	Gindai	Ehu	Onaga	Lehi	Hapuupuu
hard-high	55	44	21	27	27	50	39
hard-low	62	42	19	41	41	46	24
soft-high	42	36	13	17	17	40	37
soft-low	20	14	7	17	17	14	5
Total	**179**	**136**	**60**	**102**	**102**	**150**	**105**
Visual	Opakapaka	Kalekale	Gindai	Ehu	Onaga	Lehi	Hapuupuu
hard-high	45	33	15	20	20	40	31
hard-low	33	21	6	16	16	25	15
soft-high	41	35	14	18	18	41	38
soft-low	60	47	25	48	48	44	21
Total	**179**	**136**	**60**	**102**	**102**	**150**	**105**

Both data sets show similar distribution patterns (mean $N_{max)}$ for each species across habitat types (figure 9 & 10). Once subjected to statistical analysis, only Opakapaka and Gindai showed significant differences ($p<0.05$; KW ANOVA) in mean N_{max} across habitats for the multibeam data while all species except Ehu and Lehi showed significant differences for visually classified habitats. Pair-wise comparisons of mean N_{max} between habitat types within a species yielded the following results. Opakapaka and Onaga showed significantly higher mean N_{max} ($p<0.05$, Mann-Whitney U-test) in hard substrates compared to low substrates. With the absence of a significant difference between hard-high and hard-low habitats for both species, there is a suggested preference for hard substrates but no slope preference (Table 3). Hard-high was the clear habitat of choice for Kalekale and Hapuupuu as a significantly higher mean N_{max} only occurred when this habitat type was compared to the three others. Gindai, despite showing significant differences among habitats in the Kruskall-Wallis ANOVA, shows a weaker

trend of preference in the Mann-Whitney U-test (Table 3). There still exists some preference for hard substrates and high slopes (Table 4). Table 4 summarizes the habitat preferences for each of the Deep 7 based on differences in mean N_{max} between habitats as classified by both multibeam and visual data.

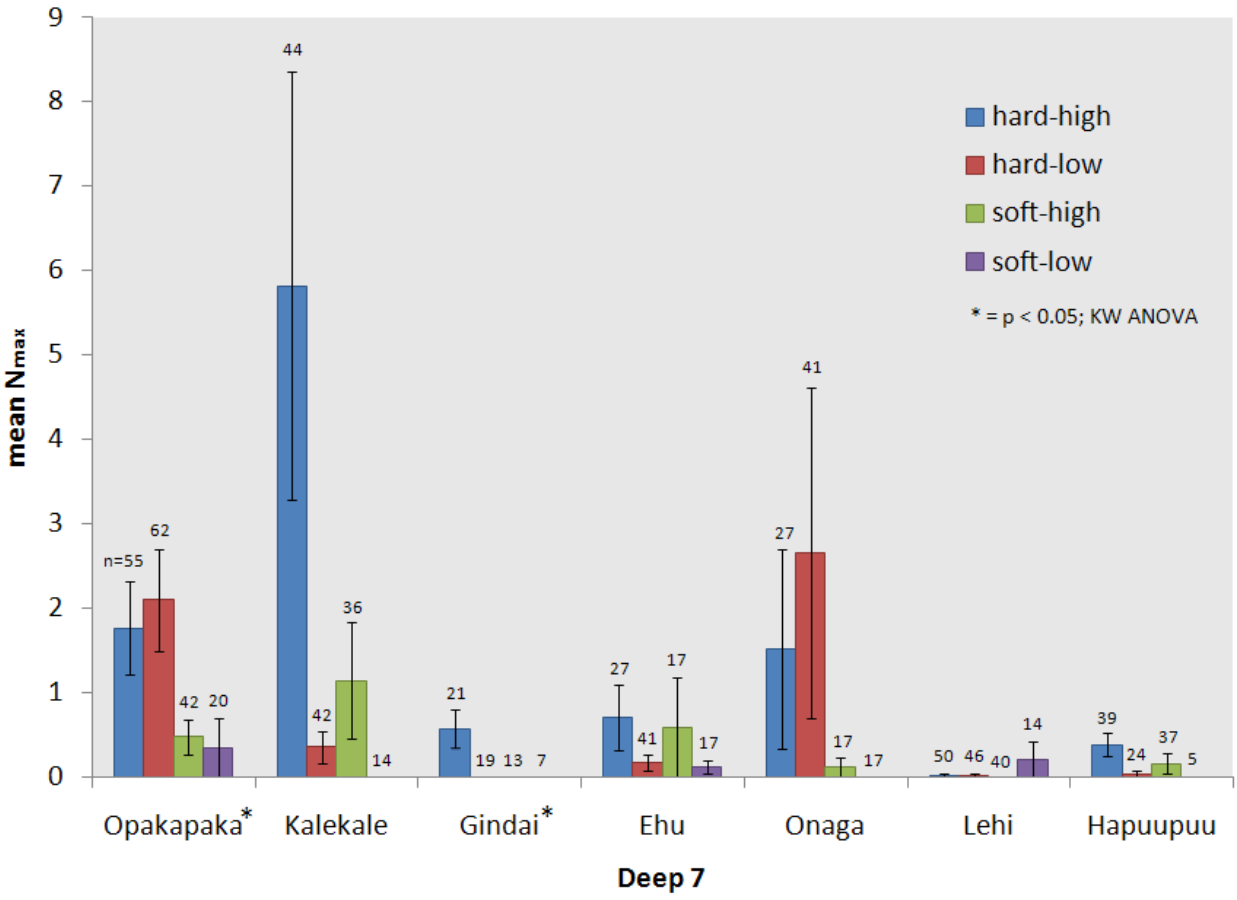

Figure 9. Deep 7 N_{max} versus multibeam classified basic habitats (" * " = $p<0.05$; KW ANOVA).

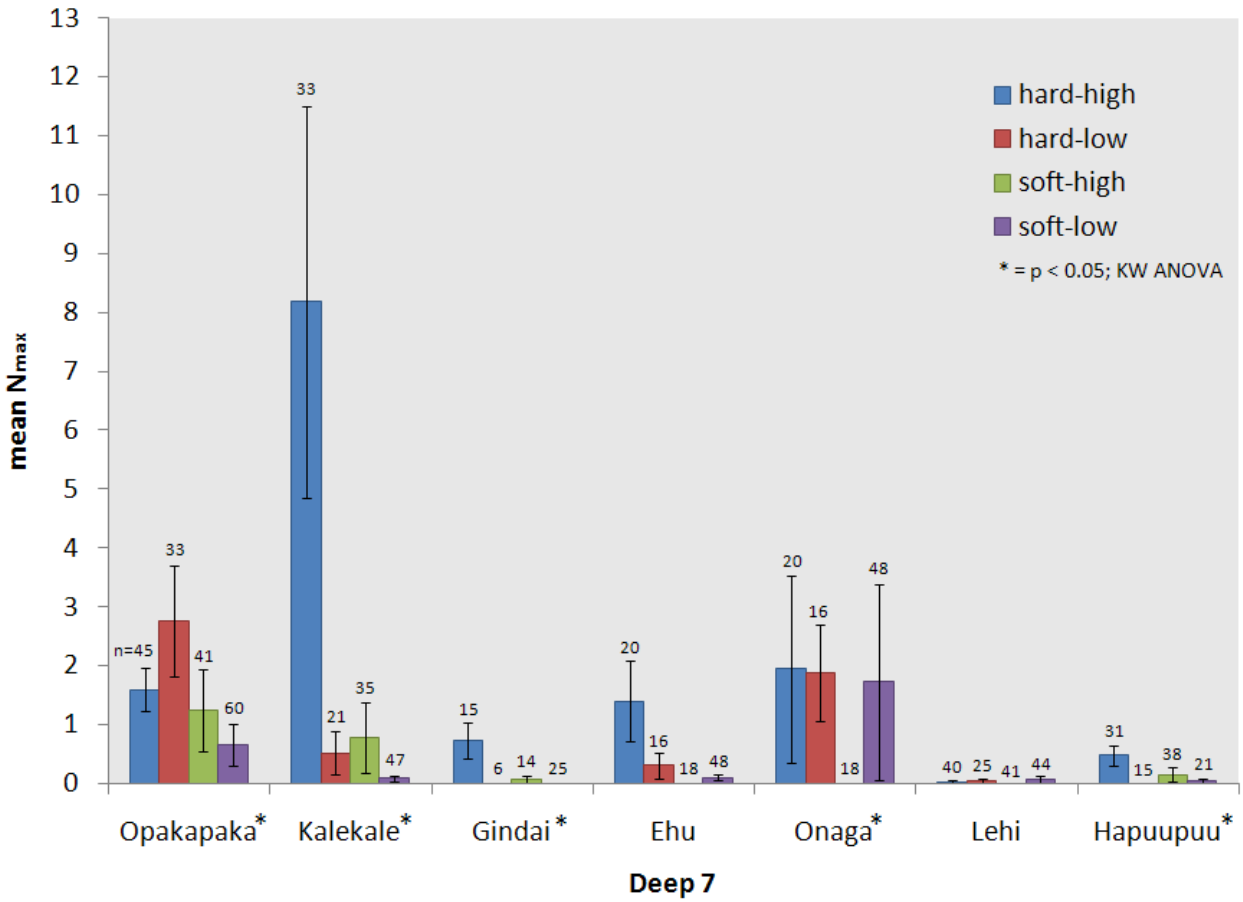

Figure 10. Deep 7 N_{max} versus visually classified basic habitats (" * " = $p<0.05$; KW ANOVA).

Table 3. Mann-Whitney U-Test pair-wise habitat comparisons

Habitat Comparisons	Multibeam Gindai	Visual Gindai	Multibeam Opakapaka	Visual Opakapaka	Visual Onaga	Visual Kalekale	Visual Hapuupuu
HH – HL	+	-	-	-	-	+	+
HH – SH	+	-	+	+	+	+	+
HH – SL	-	+	+	+	+	+	+
HL – SH	no value	-	-	-	+	-	-
HL – SL	no value	no value	+	+	+	-	-
SH – SL	no value	-	-	-	-	-	-

(HH=Hard-High, HL=Hard-Low, SH=Soft-High, SL=Soft-Low; "+" = $p<0.05$, "-" = $p>0.05$, "no value" = no fish observed in either habitat)

Table 4. Summary of habitat preferences for each of the Deep 7

Species	Depth(m)	Multibeam Data	Visual Data
Opakapaka	100-279	hard substrates	hard substrates
Kalekale	140-279	no preference	hard-high habitats
Gindai	200-259	suggestion of hard-high	suggestion of hard-high
Ehu	200-300	no preference	no preference
Onaga	200-300	no preference	hard substrates
Lehi	100-259	no preference	no preference
Hapuupuu	120-239	no preference	hard-high habitats

CHAPTER 4
DISCUSSION

The discrepancy in agreement between multibeam and visually classified habitats may be attributed to observer bias, multibeam generalization across grids, a difference in scale of observation between the two methods and possible substrate layering. When classifying habitats visually, observers make a substrate and slope determination based on videographic images. Some deployments generated dark and grainy video which increased difficulty in visual substrate determination. Strong currents such as that observed in BRFA D (Ka'ena Pt.) caused the BOTCAM to tilt to some extent making visual slope determination more challenging. These factors may have led to some observer bias in visual habitat classification. Classification by two observers was used to reduce such a bias. Multibeam mapping identifies the predominant hardness and slope of a given area. This data was used to generalize habitat classifications assigned to each grid in ArcGIS. A habitat classified as having hard substrate and high slope may therefore still have smaller areas of non-hard, non-high habitat. Furthermore, multibeam habitat classifications cover an area of 40,000 m^2 while visual habitat classifications are limited to within the BOTCAM field of view. A BOTCAM deployment may then fall within the smaller non-hard, non-high area leading to a discrepancy when multibeam and visual habitat classifications are compared. Substrate layers may also pose a problem. If a thin sediment layer covers a hard substratum, this will still be identified as being predominantly hard by multibeam mapping but visually seen as soft substrate. This may be another possible explanation for the increase in soft habitats when classifying visually.

The low agreement of hardness classifications between multibeam and visual observation can be attributed to the many possible sources of discrepancy mentioned earlier. Slope, on the other hand, is a much more straight-forward variable to determine by both methods and with only a single possible factor contributing to discrepancy there is a much higher agreement between both classification methods.

Despite only a 61.5 percent agreement between multibeam classified habitats and visually classified habitats, the similarity in distribution confirms an existence of habitat preferences. The hypothesis that each of the Deep 7 shows a preference for hard substrates and high slopes only holds true for Kalekale and Hapuupuu. Gindai exhibited a tendency towards hard-high habitats which is consistent with the findings of Seki and Callahan (1988) who noted that Gindai normally inhabit escarpments with high vertical relief. Kalekale, Hapuupuu and Gindai are therefore the only species that exhibit at least some preference for a combination of hard substrates and high slope which has been identified as suitable bottomfish habitat by Parke (2007). Studies by Polovina et al. (1985), Haight et al. (1993a), Moffit (1993) and Kelley et al. (2006) all confirm the presence of deepwater snappers and groupers in such habitats. On the other hand, Opakapaka and Onaga, contrary to previous findings, showed only a preference for hard substrates and no slope preference. The Opakapaka has been widely studied in both its juvenile and adult stages. Juveniles have been found in flat, featureless habitats up to 100 meters in depth and then concentrate around high relief features in deeper waters after leaving their nursery grounds (Moffitt and Parrish, 1996). Since no fish measurement data was available during the time of this study, it was not determined whether the observed Opakapakas were juveniles or adults. This may account for the absence of a

slope preference if both juveniles and adults were actually present. Lehi and Ehu, on the other hand, showed no significant habitat preference. For Lehi, this may be attributed to the scarcity of fish of this species.

Feeding ecology and life history of a species may very well be the reason for the observed habitat preferences. Two feeding guilds of deepwater snappers were identified by Haight et al. (1993b): a planktivorous guild that fed primarily on zooplankton and a piscivorous guild that fed on fish in the mesopelagic boundary community. Opakapaka and Kalekale were found to be primarily planktivorous while Onaga and Ehu were primarily piscivorous. Gindai was classified as demersal carnivore by Seki and Callahan (1988) as it preyed heavily upon benthic and demersal invertebrates and fishes. Hapuupuu was also identified as being primarily piscivorous by Seki (1984). Benthic fishes and other bottom inhabitants were present in the Hapuupuu diet. Data on the feeding ecology of Lehi was again scarce and Lehi was even absent in the deep water snapper feeding studies conducted by Haight et al. (1993b) in Penguin Banks.

If habitat preferences are a function of feeding ecology, the likely assumption would be that prey concentrate or are more available over the habitat of preference of a given species of bottomfish. For the piscivorous snappers, Haight et al. (1993b) found a good correspondence between the depth range of prey fish and the depth where snappers were captured. This shows a positive correlation between the presence of prey and the presence of deep water snappers although no habitat association was implied. Ralston et al. (1986) found that deepwater snappers were most abundant on slopes near underwater headlands at Johnston Atoll and attributed this abundance to high planktonic

concentrations created by mesoscale oceanographic processes relative to the bottom features. Haight et al. (1993b) also postulated that as deeper currents encounter areas of high relief, an increase of local plankton abundance may be observed. Such an event could explain the hard-high habitat preference of Kalekale because of its planktivorous nature. Hapuupuu and Gindai, being demersal feeders, are likely benefit from the presence of hard substrates as this may serve as prime habitats for benthic prey organisms. But because they also incorporate non-fish prey into their diet, increased planktonic concentrations as a result of high relief areas would be a likely reason for their high slope preference. Some mesopelagic fish that perform diel vertical migration have been found in Ehu and Onaga diets (Haight et al., 1993b). Gordon (2001) in his study of Atlantic deepwater fisheries found that benthopelagic food sources impinge vertically and horizontally onto a slope during migration. The absence of slope preference in both Ehu and Onaga therefore leads to the conclusion that the feeding ecology of these species may not be the only factor affecting habitat preference where observed.

The deep 7 are also preyed upon by other organisms higher up on the deep sea food chain. Sharks and even the Kahala (*Seriola dumerili*) are known to prey on some of the deep 7 species. First hand observations of Kahala preying on Ehu have been made during submersible dives in the Hawaiian Islands by Chris Kelley of the Hawaii Undersea Research Laboratory (Kelley, unpublished data). These bottomfish may therefore utilize their habitat as a refuge from predatory species. Hard substrates with high relief may provide such a refuge but the presence of cavities in high complexity bedrock as described by Kelley et al. (2006) may be a more important factor presumably because it offers more effective shelter against predators. This brings us back to the need

for further habitat characterization that includes a description of the substrate types and the presence or absence of cavities. Migration patterns of bottomfish species, reproductive behavior and environmental tolerances should also be looked into so that we may better understand the ecology of these commercially important fish species.

In an attempt to assess the appropriateness of current BRFA locations, the relative areas of basic habitat types (100 to 300 meters) of each BRFA were calculated. With 3 of the 7 species studied showing a preference for hard-high habitats, a high percentage of such a habitat type within a BRFA would be ideal. 14.4 % of BRFA B, 0.1% of BRFA D and 1.7% of BRFA E are hard-high habitats (figure 11) and give us some insight into the appropriateness of the delineations of these BRFAs. Parke (2007) illustrates the size and location of areas around the main Hawaiian Islands that meet all criteria for what he describes as sustainable bottomfish habitat equivalent to habitats classified as hard-high in this study. Only on the west coast of Niihau is there more hard-high habitat within the 100-300 meter depth range that may possibly be considered a more appropriate location for a BRFA. On the island of Oahu hard-high habitats are scarce and other factors played a role in the BRFA site selection. BRFA E encompasses a known Onaga breeding ground (Kelley, unpublished data) making it a prime location for protection based on the 1996 Magnusson-Stevens Fishery Conservation and Management Act EFH definition despite the disparity of hard-high habitats (figure 11). With 19.7 % hard-low habitat within BRFA E, this BRFA still holds some relevance in protecting Opakapaka and Onaga who have shown a preference for hard substrates. A high proportion of hard-high and hard-low habitats within a BRFA would then successfully protect habitats preferred by 5 species of the Deep 7.

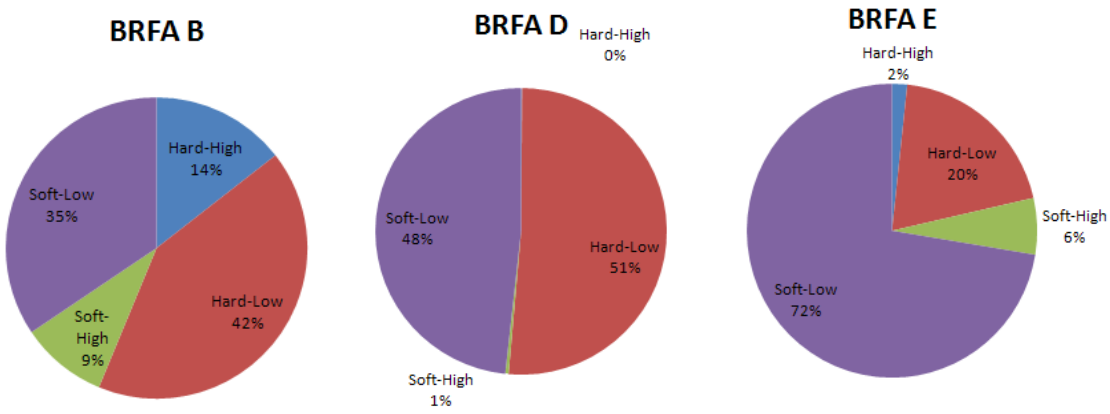

Figure 11. Percentages of basic habitats within the 100 to 300 meter depth gradient inside BRFA B, BRFA D and BRFA E.

Data from this study may aid in the redefinition of the EFH for Hawaii's bottomfish complex. There is clear concurrence with the definition of a suitable bottomfish habitat by Parke (2007) for Kalekale, Gindai and Hapuupuu. For the rest of the species with a significant number of observations, Opakapaka and Onaga showed only a preference for hard substrates while Ehu did not show any preference at all. The Opakapaka, Onaga and Ehu results bring new insight into the ecology of these species and moves us away from the notion that all bottomfish exhibit similar habitat preferences. The definition of an ideal habitat for the entire bottomfish complex is therefore insufficient in the management of this multi-species fishery. Unfortunately, with the difficulty in specifically characterizing deep sea habitats over large areas and the lack of knowledge on the ecology of these bottomfish, species-specific EFH definitions may not be attainable just yet. Further studies that address other habitat characteristics (substrate

types, presence of cavities, current direction), prey-habitat associations and movement patterns of commercial bottomfish would be necessary to improve our understanding of the species in this fishery. With the data available at this time, new elements such as hardness of substrate and slope may then possibly be included in a further modified EFH definition for Hawaii bottomfish to improve the ecological management approach. EFH definitions are designed to guide management decisions on the protection and sustainable exploitation of fishery resources and therefore need to be as complete and as specific as possible (Kelley et al., 2006). A redefinition of the current Essential Fish Habitat would likely be the first step towards better management of Hawaii's bottomfish fishery.

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